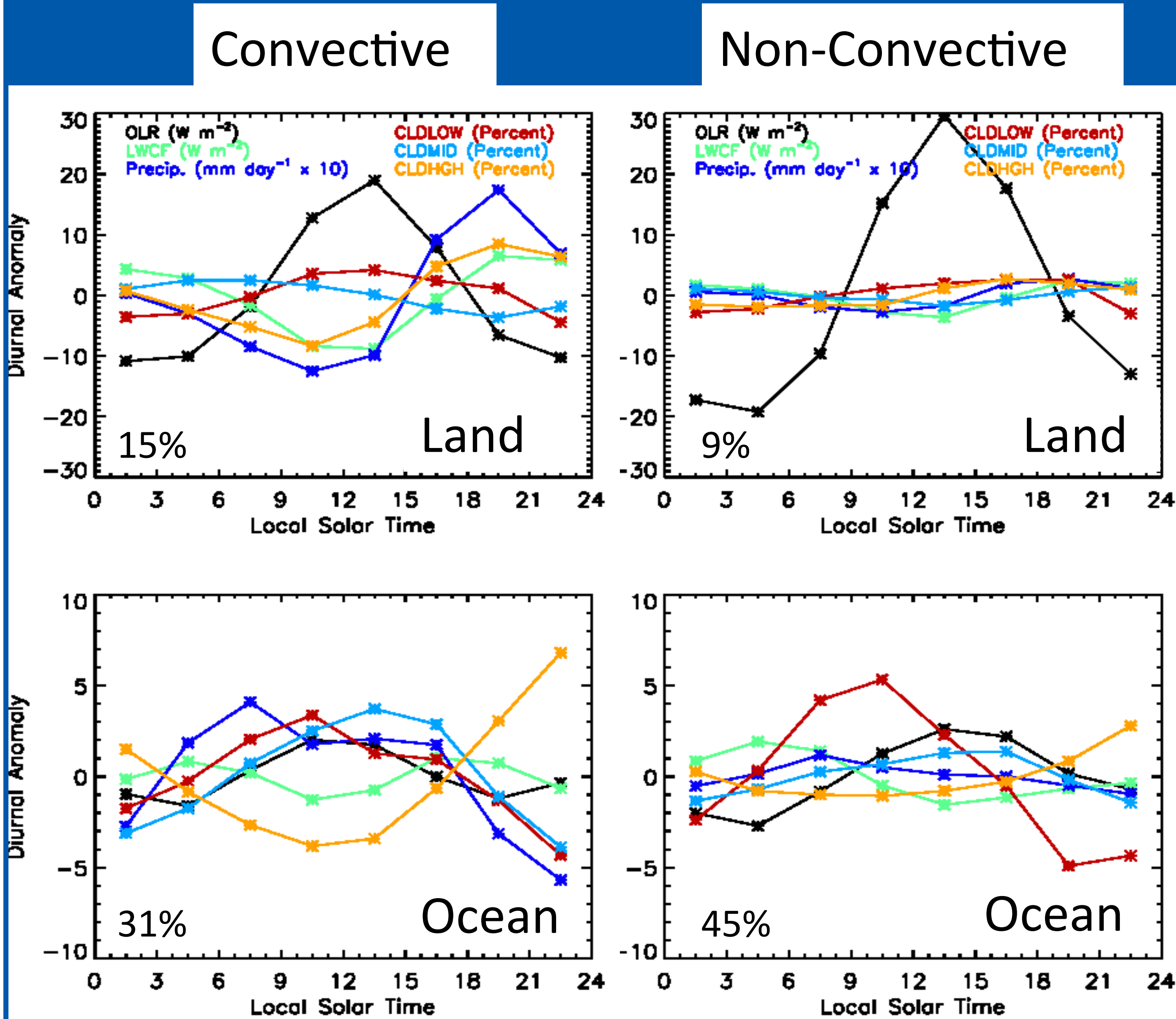
Variability of Monthly Diurnal Cycle Composites of TOA Radiative Fluxes in the Tropics

Patrick Taylor
NASA Langley Research Center
Climate Science Branch
CERES STM
May 9, 2013

Motivation

- The diurnal cycle is a fundamental earth system variability.
- Significant diurnal cycle signals are evident in many geophysical datasets, including temperature, water vapor, clouds, radiation, and convective precipitation (e.g., Minnis and Harrison 1984a,b,c; Randall et al. 1991; Janowiak et al. 1994; Bergman and Salby 1996; Lin et al. 2000; Soden 2000; Yang and Slingo 2001).
- The diurnal cycle is traditionally thought to be the result of a long time average removing “weather noise.”

Background: Diurnal Cycle Regimes



- Convective and non-convective regimes are determined using climatological High Cloud amount (e.g., Bergman and Salby 1996).

- Convective:
High cloud > 10 %
- Non-Convective:
High cloud < 10 %

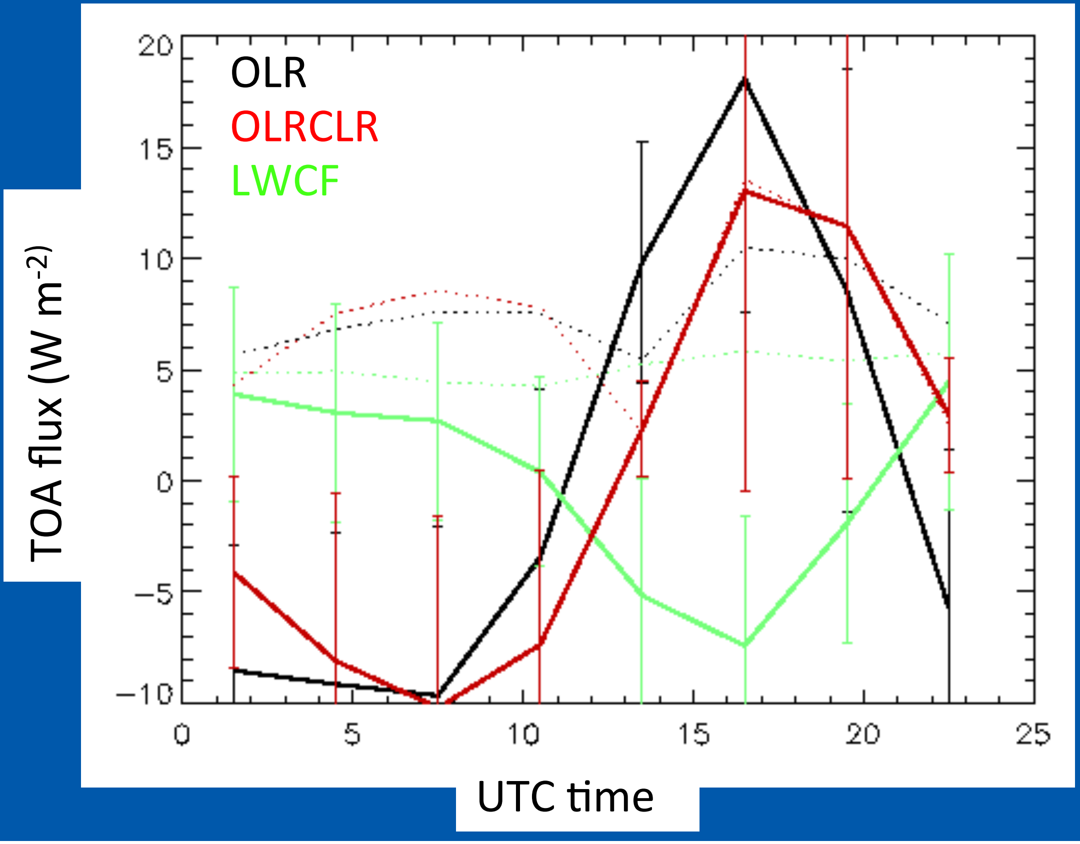
Traditional diurnal cycle regimes provide a statistically robust categorization.

Main Points

- Point 1: The TOA flux (and cloud) diurnal cycle is variable.
- Point 2: Diurnal cycle variability in TOA flux is driven by clouds.
- Point 3: Neglecting this variability leads to uncertainty and bias.
- Point 4: Variability in the diurnal cycle is related to variability in atmospheric dynamic and thermodynamic state.

Diurnal cycle variability defined

The monthly, 3-hour composite of a variable differs from month-to-month outside of the random, statistical variations.



Data

- CERES SYN Ed2rev1:
  - Synergistically combines CERES and GEO observations to create a 3-hourly data product by using GEO radiances to obtain diurnal shape and CERES for radiometric accuracy:

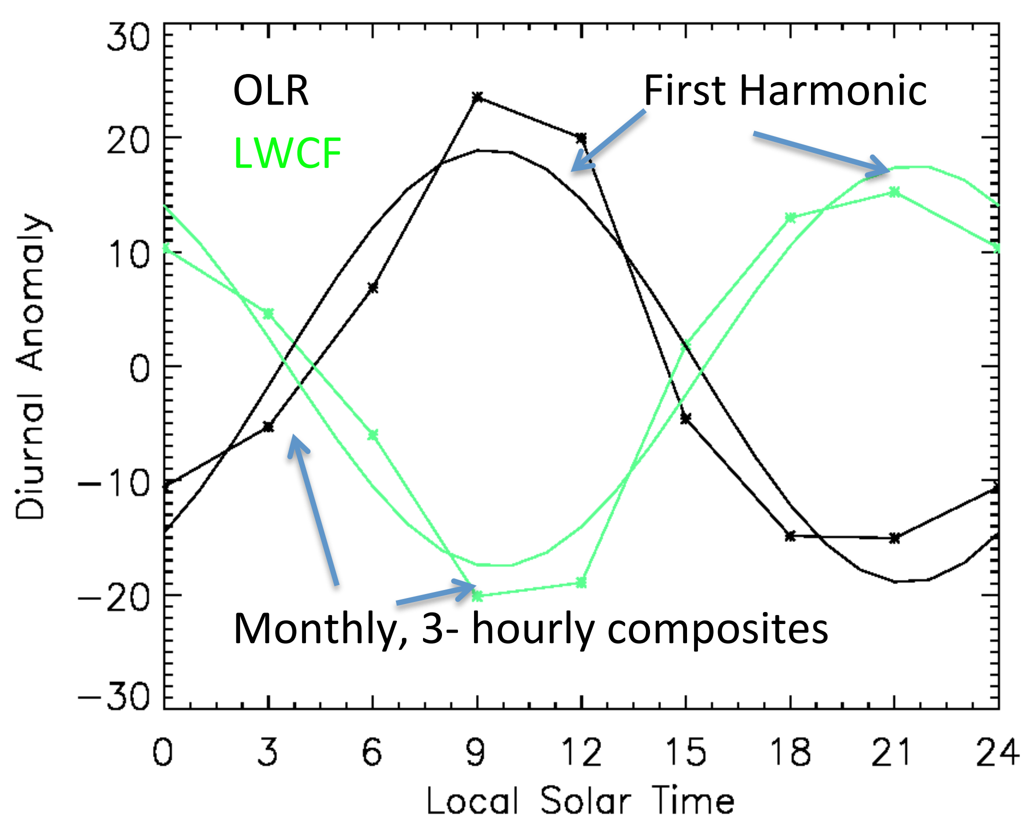
  (1) A calibration of each GEO instrument with MODIS imager data

  (2) A narrowband radiance to broadband radiance conversion

  (3) An integration of GEO broadband radiance to irradiance

  (4) A normalization of GEO derived flux to observed CERES flux.

Method: Diurnal Harmonic

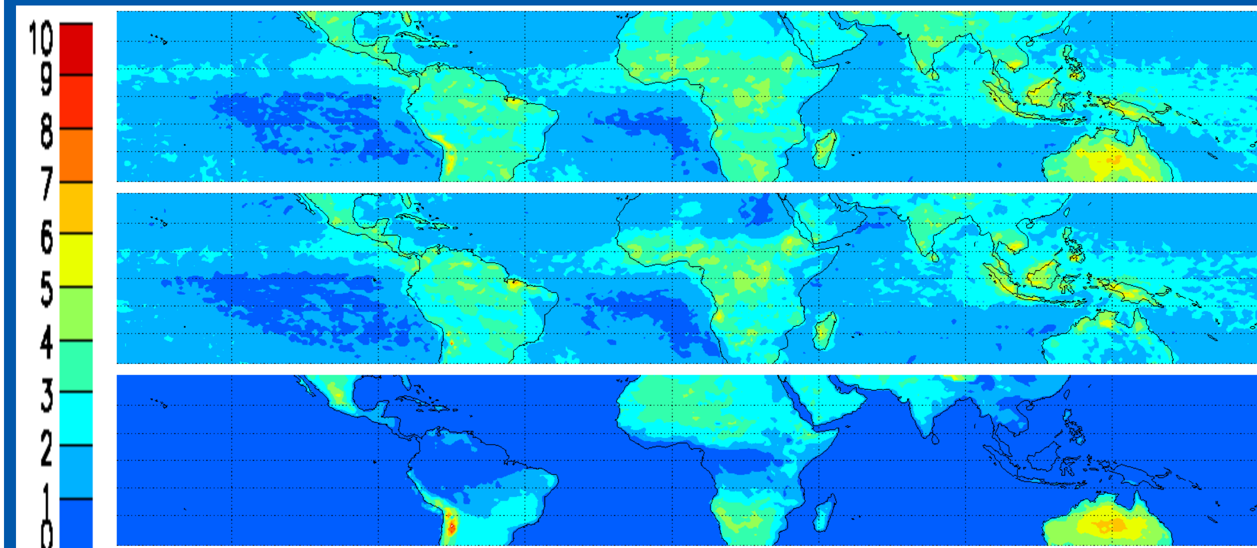


$$X'(t) = A\cos\left(\frac{2\pi t}{24\,hrs} - \phi\right)$$

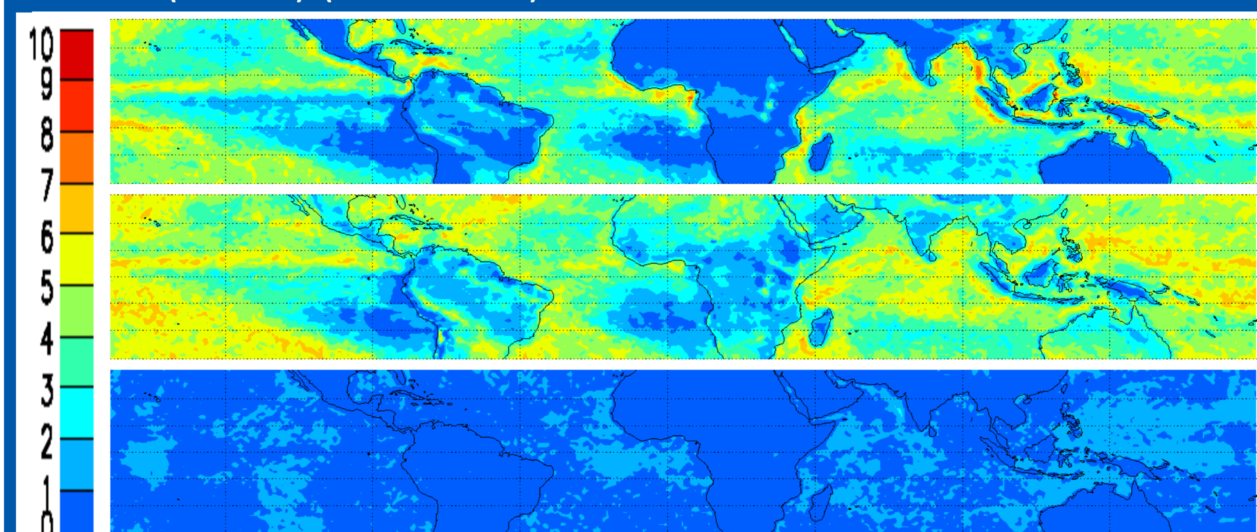
- CERES Synoptic Data
  - 3-hourly CERES-Geo merged data product.
- Fourier analysis is used to compute diurnal harmonics.

OLR Diurnal cycle variability

STDEV(Amplitude) (unit: W m^{-2})



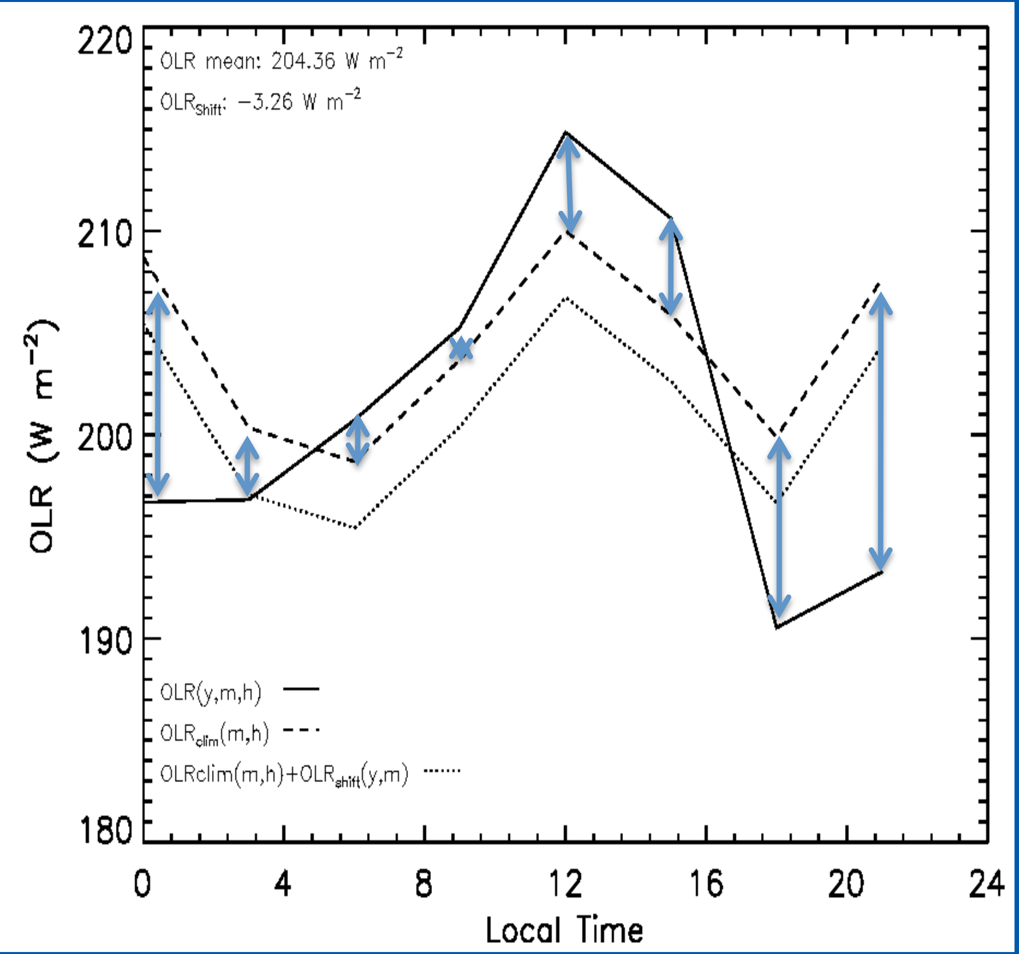
STDEV(Phase) (unit: hour)



- Fourier harmonic analysis is used by fitting a cosine function to monthly, 3-hourly composites of OLR, LWCF, and OLRCLR.
- The seasonal cycle of the monthly data set is removed and the STDEV is shown here to represent diurnal cycle variability.

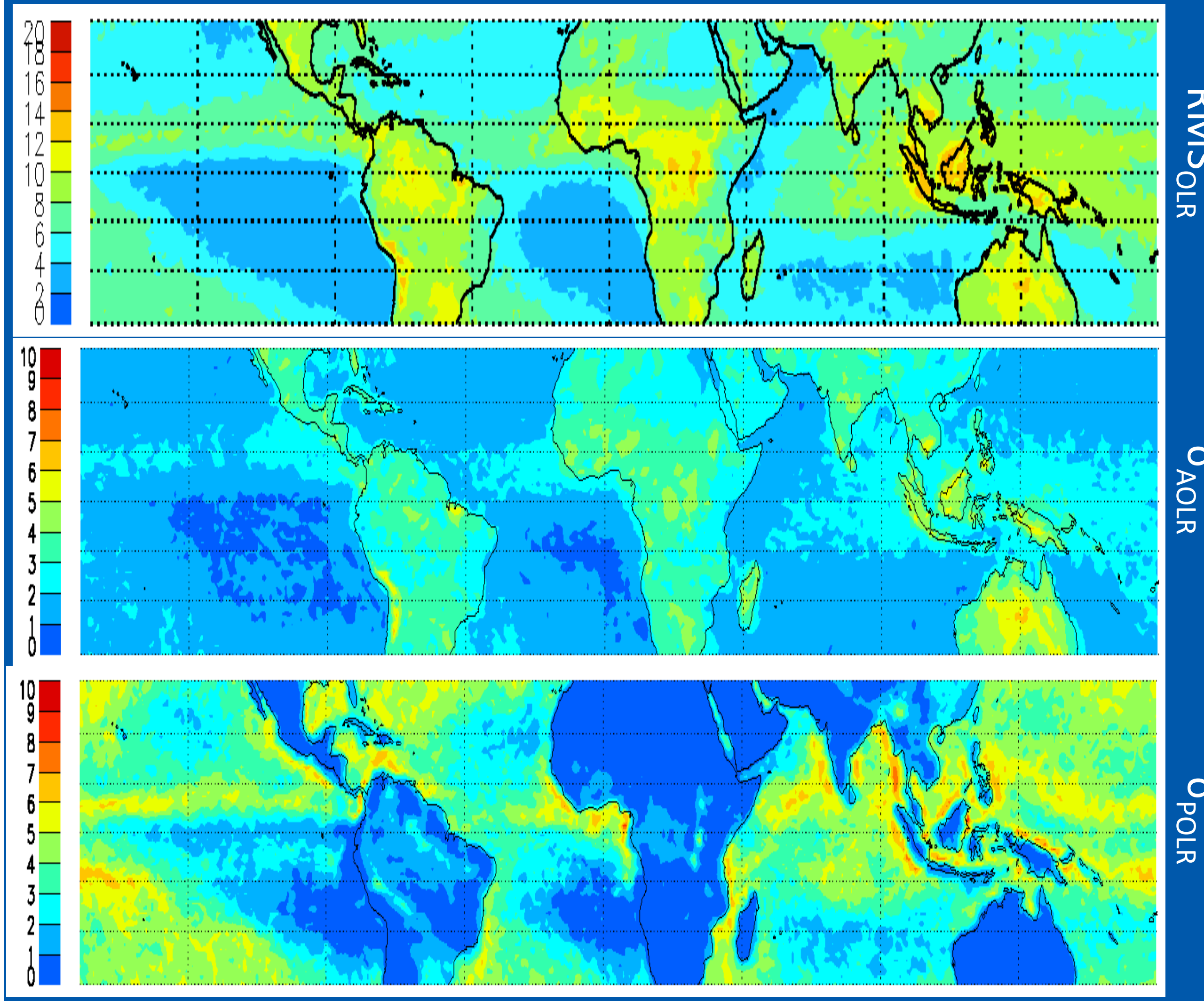
Alternative diurnal cycle variability metric (RMS)

- Because of the RSW structure, a Fourier first harmonic fit does not characterize the diurnal cycle well.
- Therefore, an alternative method is developed to characterize RSW diurnal cycle variability.



$$RMS_{DC}(m) = \sqrt{\frac{1}{N}\sum_{h=1}^{N}(RSW(m,h) - RSW_{clim}(m,h))^2}$$

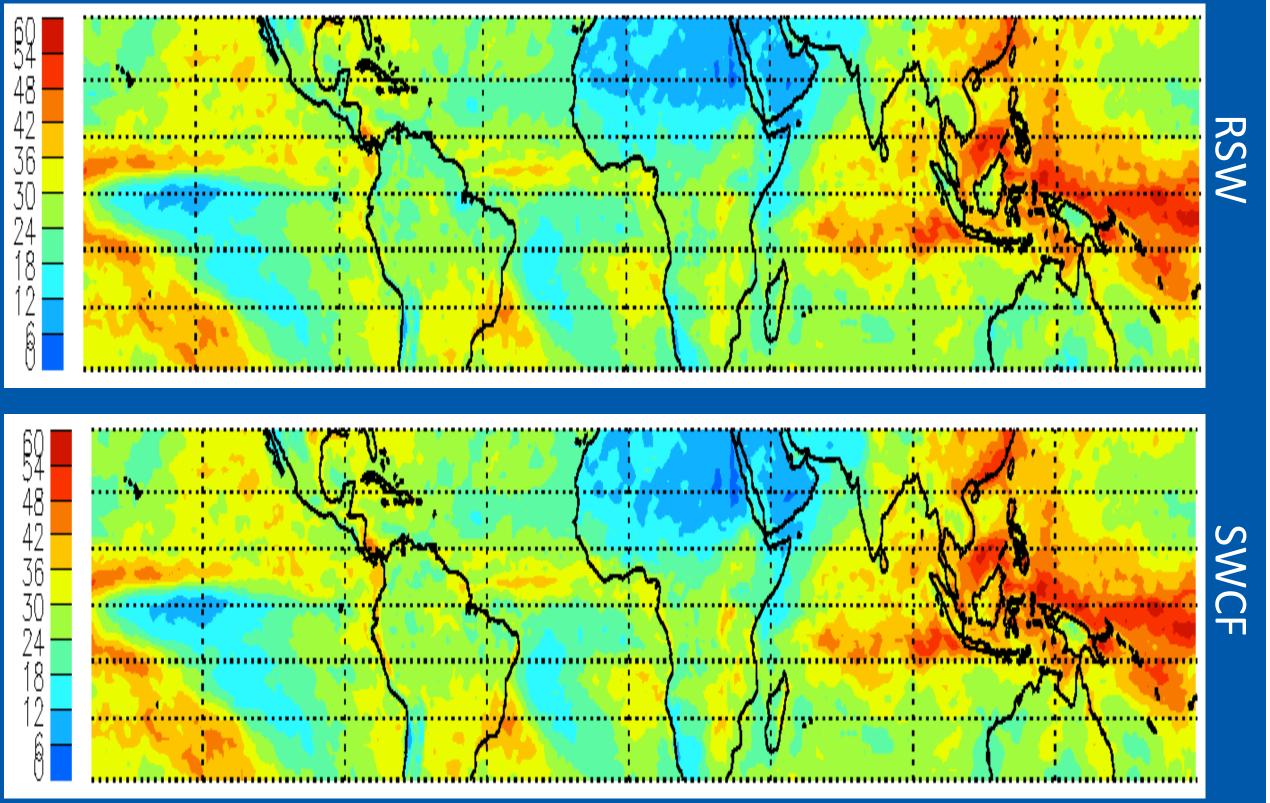
Harmonic vs. RMS Method: OLR



- These plots present a comparison between the harmonic and RMS diurnal cycle metrics.
- The same regions are highlighted in both the harmonic and RMS methods.
- The main point here is that the RMS method cannot distinguish between amplitude and phase contributions.

RSW diurnal cycle variability: RMS_{RSW} and RMS_{RSW}

- The RSW diurnal cycle is highly variable in regions of oceanic convection and moderately variable over land convective and ocean non-convective regions.
- The variability is very small over land non-convective regions.
- The diurnal cycle variability in the RSW diurnal cycle is entirely due to clouds.



Assessing uncertainty from neglecting diurnal cycle variability: TOA flux

(1) Create a simulated data set with diurnal cycle variability removed.

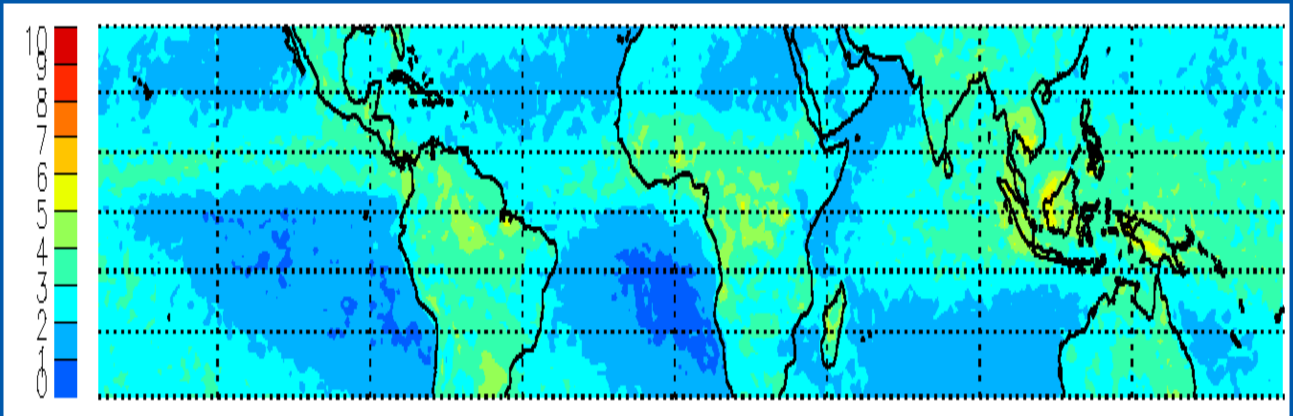
$$OLR_{sim}(m,h) = OLR(m,h_{obs}) * \frac{OLR_{clim}(m,h)}{OLR_{clim}(m,h_{obs})}$$

(2) Compare against "truth" data set (CERES SYN Ed2rev1)

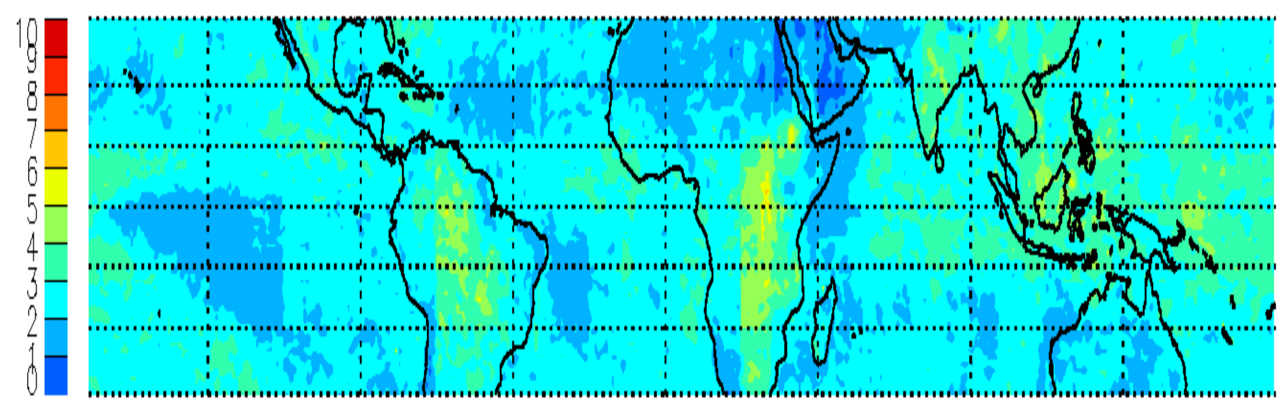
$$OLR_{unc} = \sqrt{\frac{1}{N}\sum_{m=1}^{N}(OLR_{sim}(m) - OLR_{obs}(m))^2}$$

Neglecting Diurnal Cycle Variability: Uncertainty

OLR



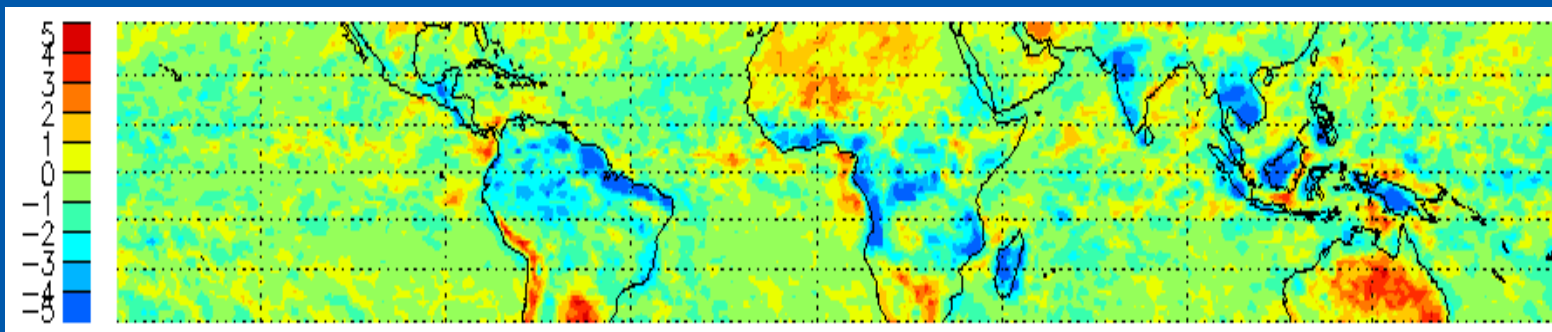
RSW



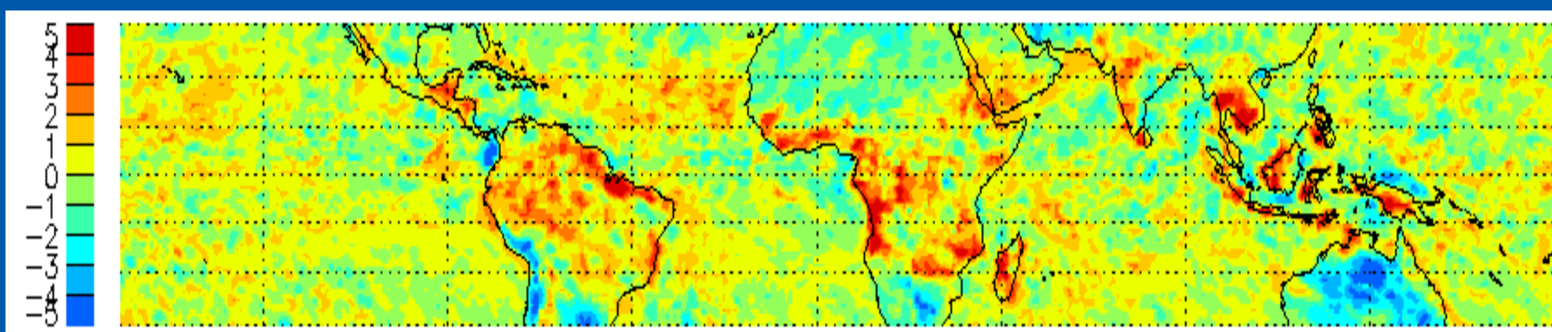
Uncertainty in monthly mean OLR and RSW fluxes ranges from 1-7 Wm^{-2} across the tropics (Taylor 2013, submitted).

Neglecting Diurnal Cycle Variability: OLR Bias

OLR’ > +1σ



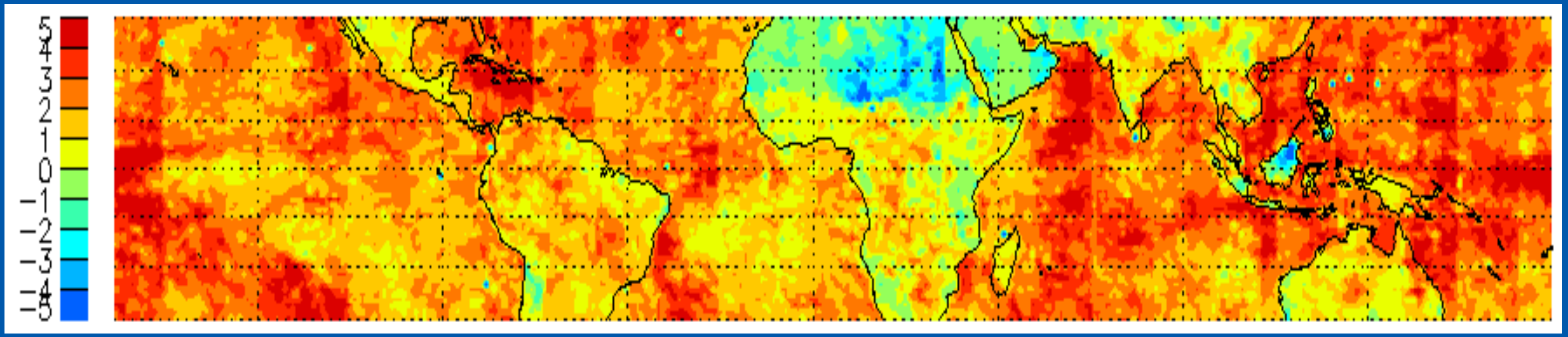
OLR’ < -1σ



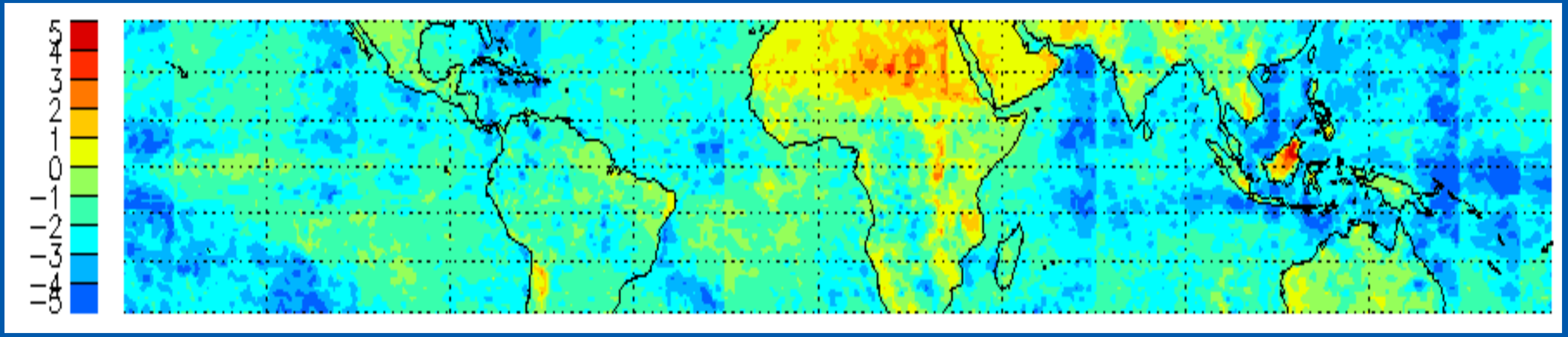
Systematic bias ranges from +5 to -5 W m^{-2} when sorted by magnitude of OLR’ (Taylor 2013, submitted).

Neglecting Diurnal Cycle Variability: RSW Bias

RSW’ > +1σ

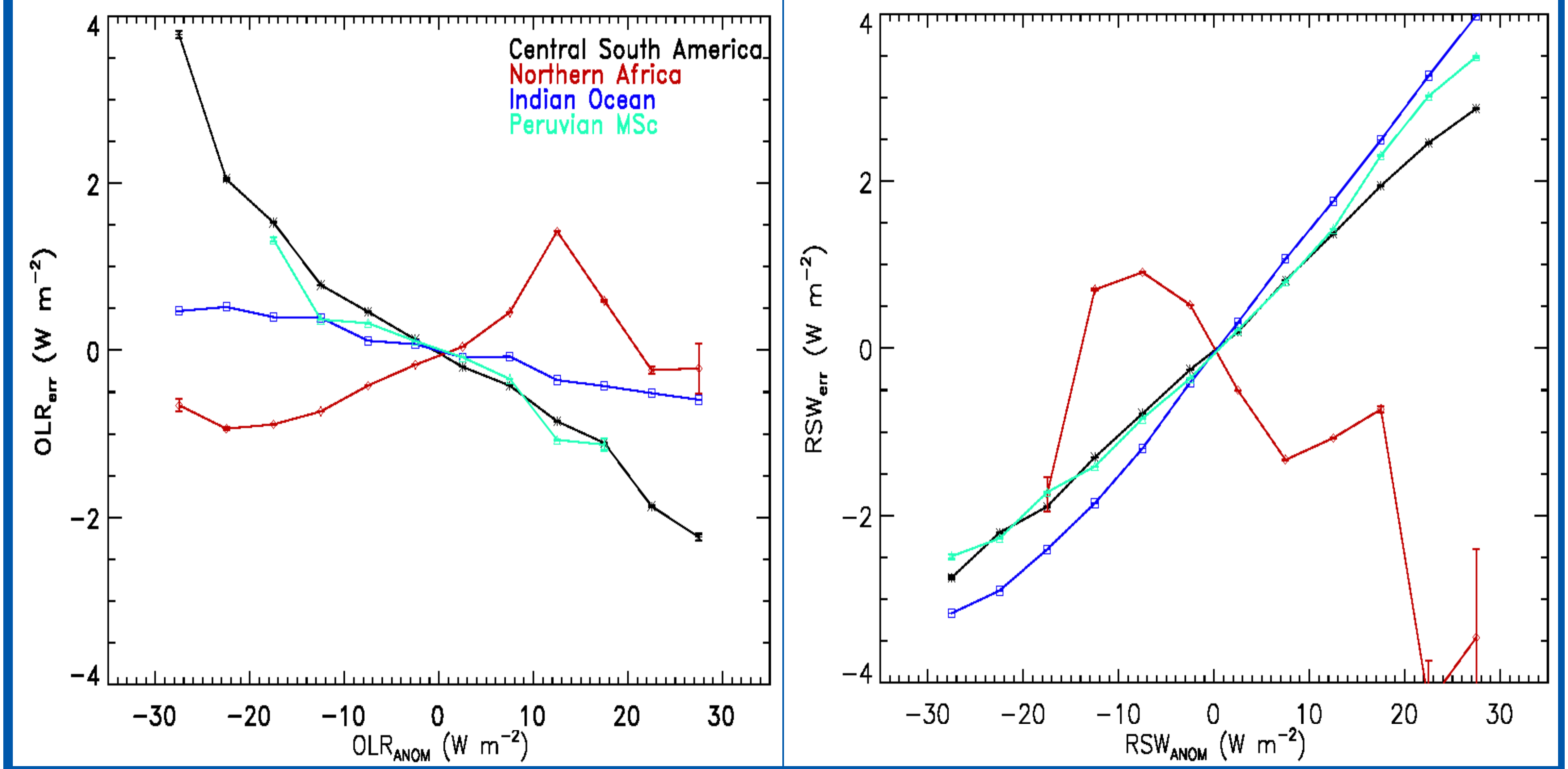


RSW’ < -1σ



Similar to OLR, systematic bias ranges from +5 to -5 W m^{-2} when sorted by magnitude of RSW’.

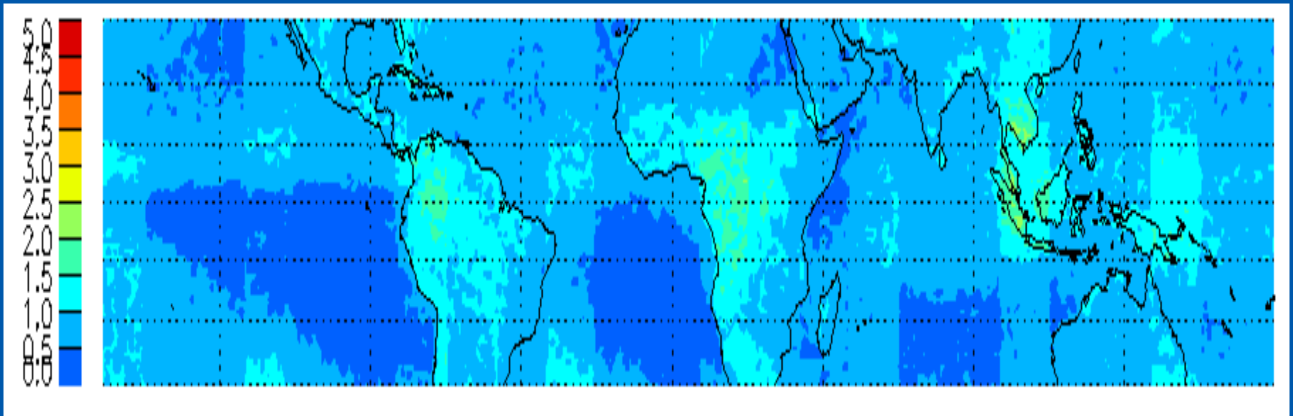
Regional Behavior of OLR and RSW bias



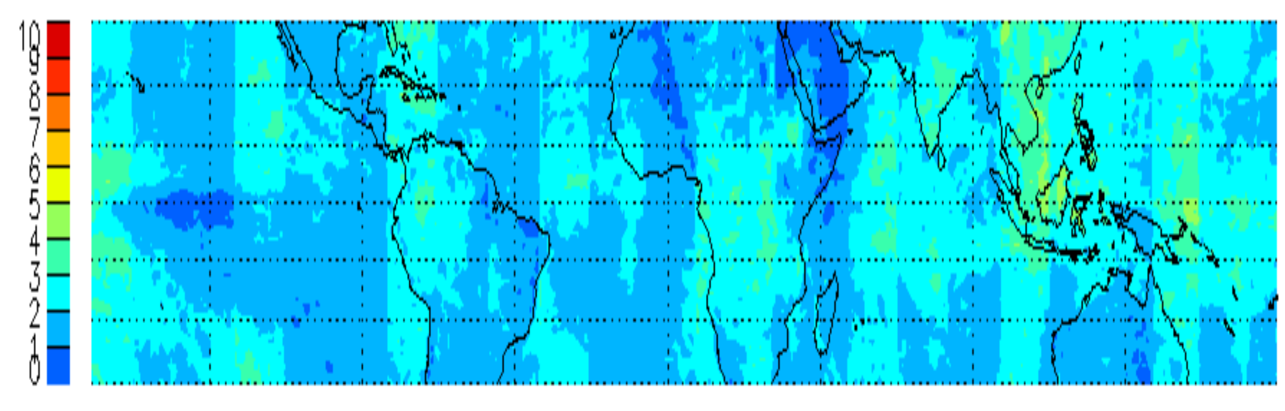
Shown is the regional difference between OLR_{sim} and OLR_{obs} and RSW_{sim} and RSW_{obs} sorted by monthly OLR and RSW anomaly, respectively.

Neglecting Diurnal Cycle Variability: Uncertainty—Two Observations

OLR

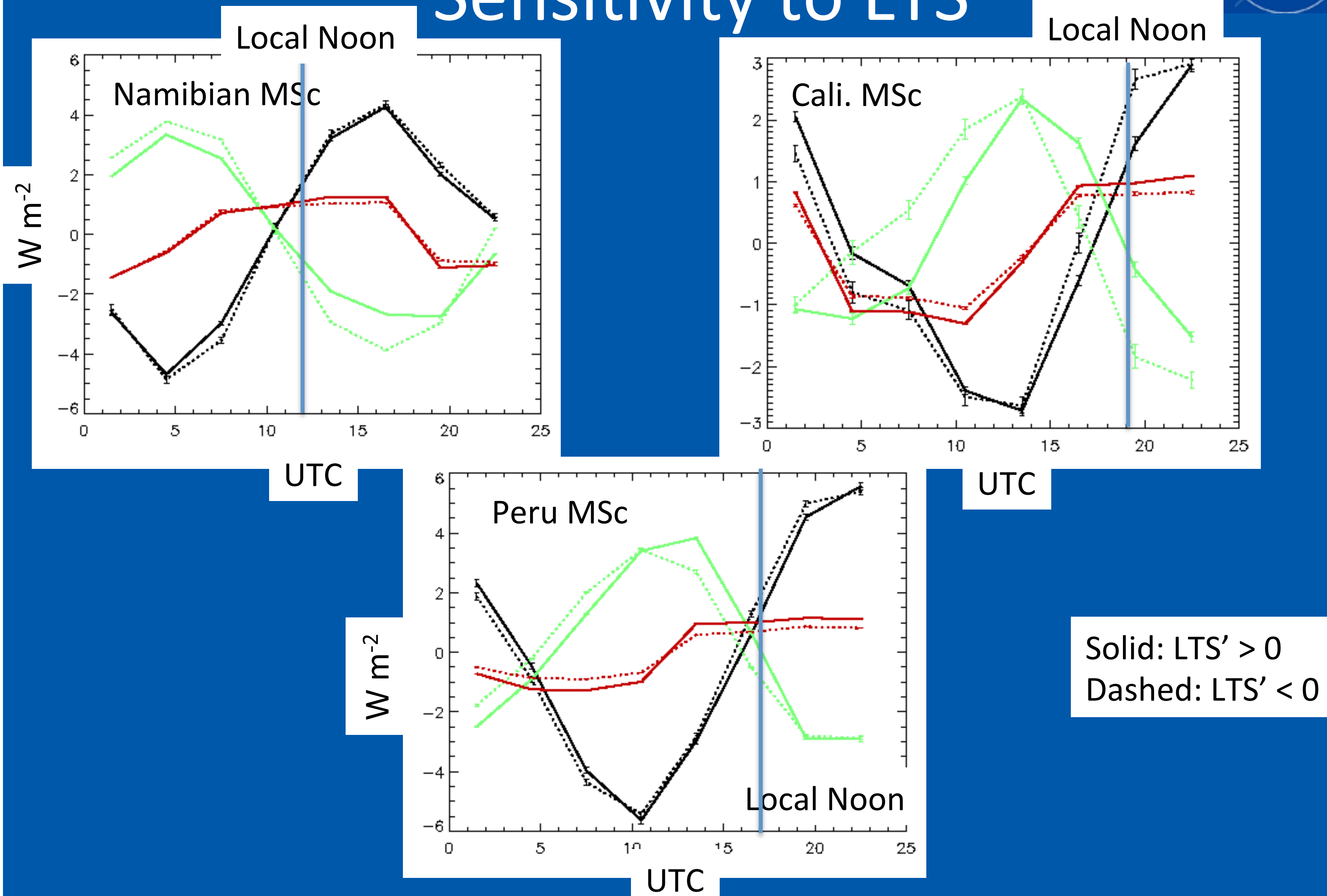


RSW



Uncertainty in monthly mean OLR and RSW fluxes changes from 1-7 Wm^{-2} to 1-5 Wm^{-2} (Taylor 2013, submitted).

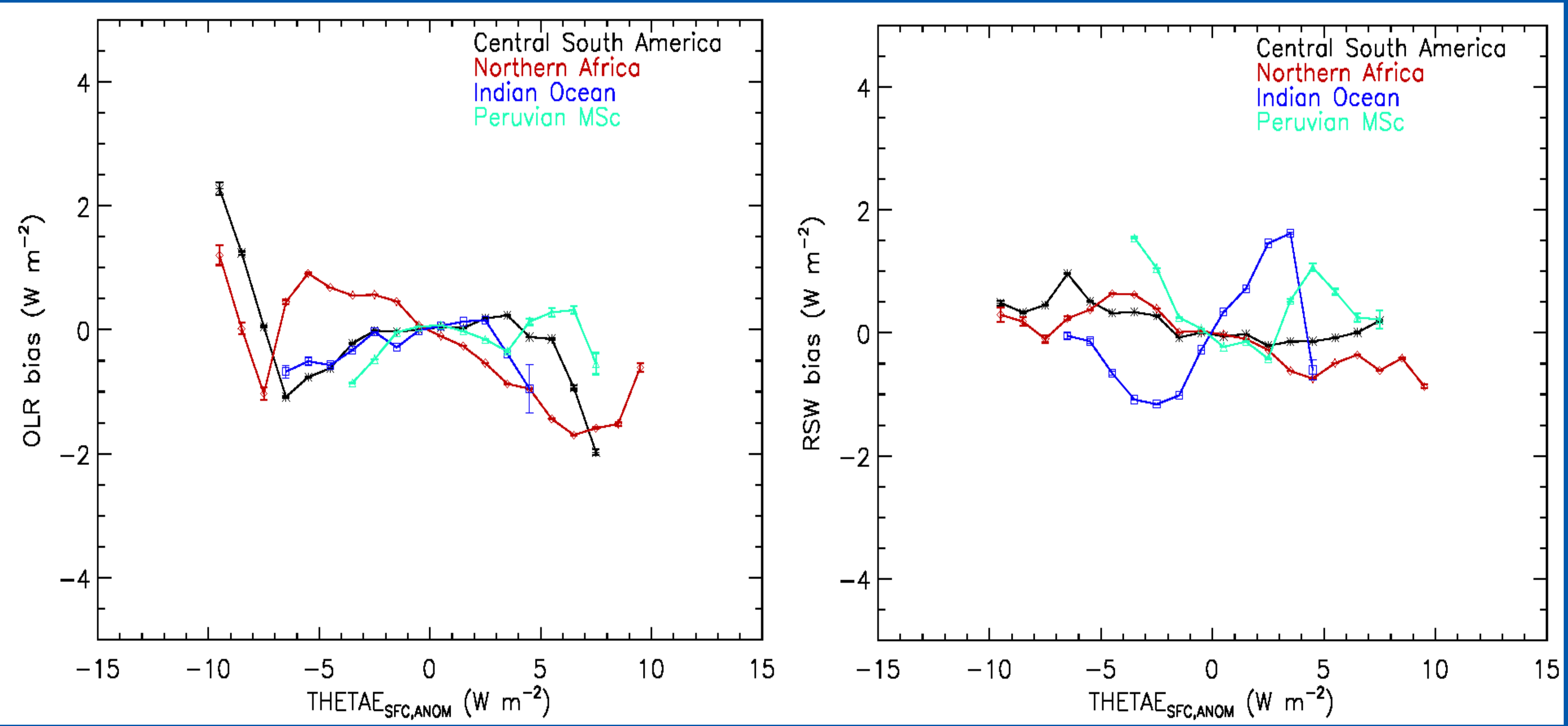
Low cloud diurnal cycle: Sensitivity to LTS



Main Points

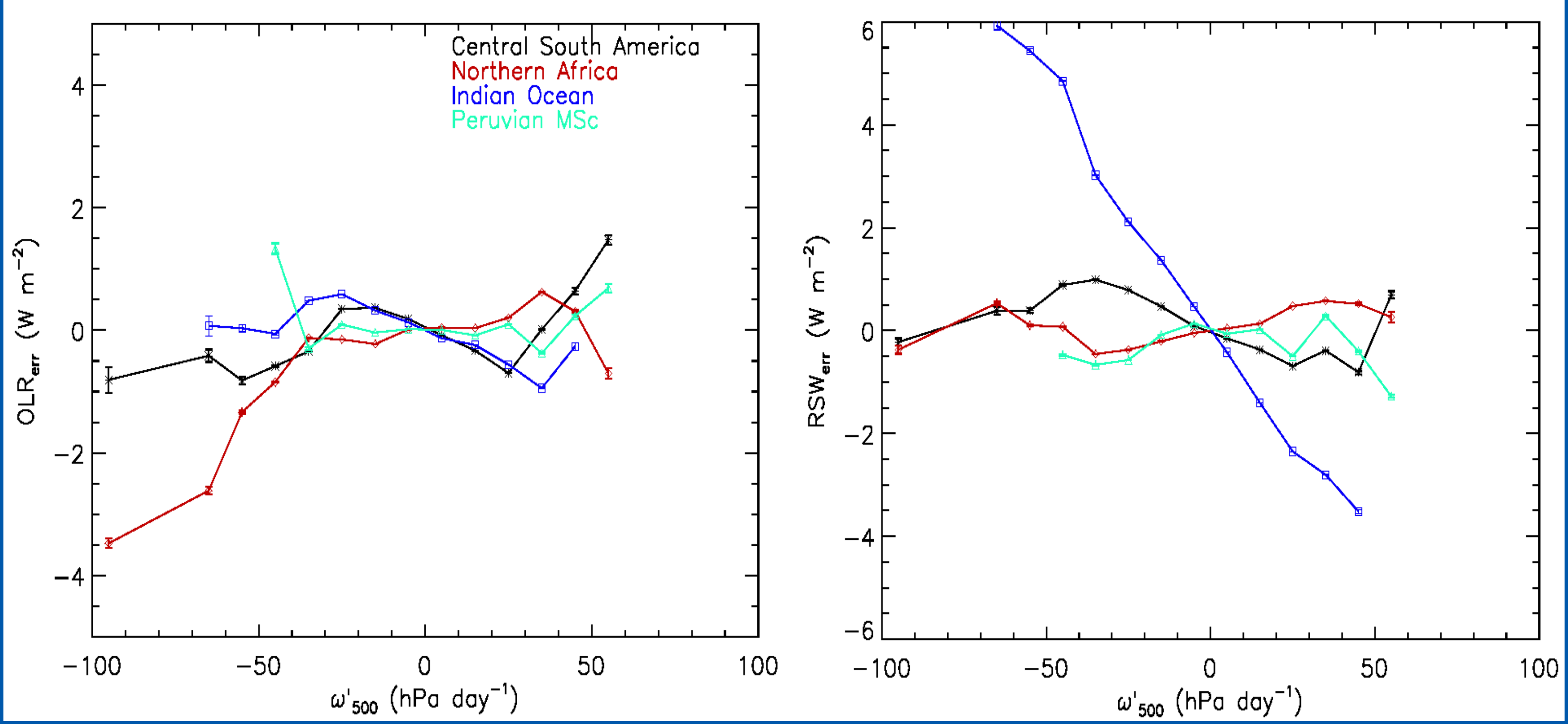
- Point 1: The TOA flux (and cloud) diurnal cycle is variable.
- Point 2: Diurnal cycle variability in TOA flux is driven by clouds.
- Point 3: Neglecting this variability leads to uncertainty and bias.
- Point 4: Variability in the diurnal cycle is related to variability in atmospheric dynamic and thermodynamic state.

OLR_{err} and RSW_{err} sorted by atmospheric thermodynamic state



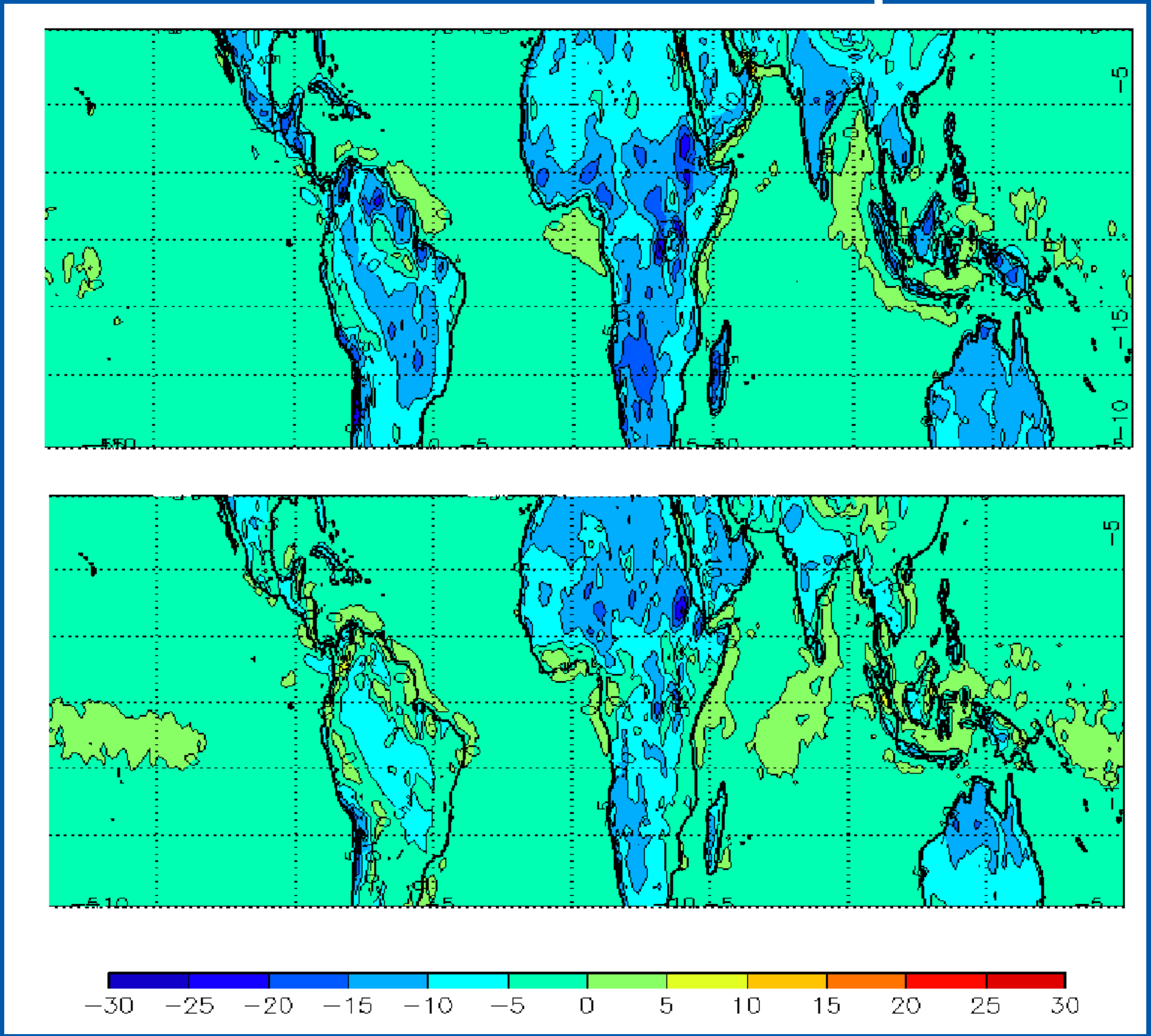
Shown is the regional difference between OLR_{sim} and OLR_{obs} and RSW_{sim} and RSW_{obs} sorted by the monthly $THETA_{E,SFC}$ anomaly.

OLR_{err} and RSW_{err} sorted by atmospheric dynamic state



Shown is the regional difference between OLR_{sim} and OLR_{obs} and RSW_{sim} and RSW_{obs} sorted by the monthly ω_{500} anomaly.

Reanalysis diurnal cycle bias: OLR amplitude

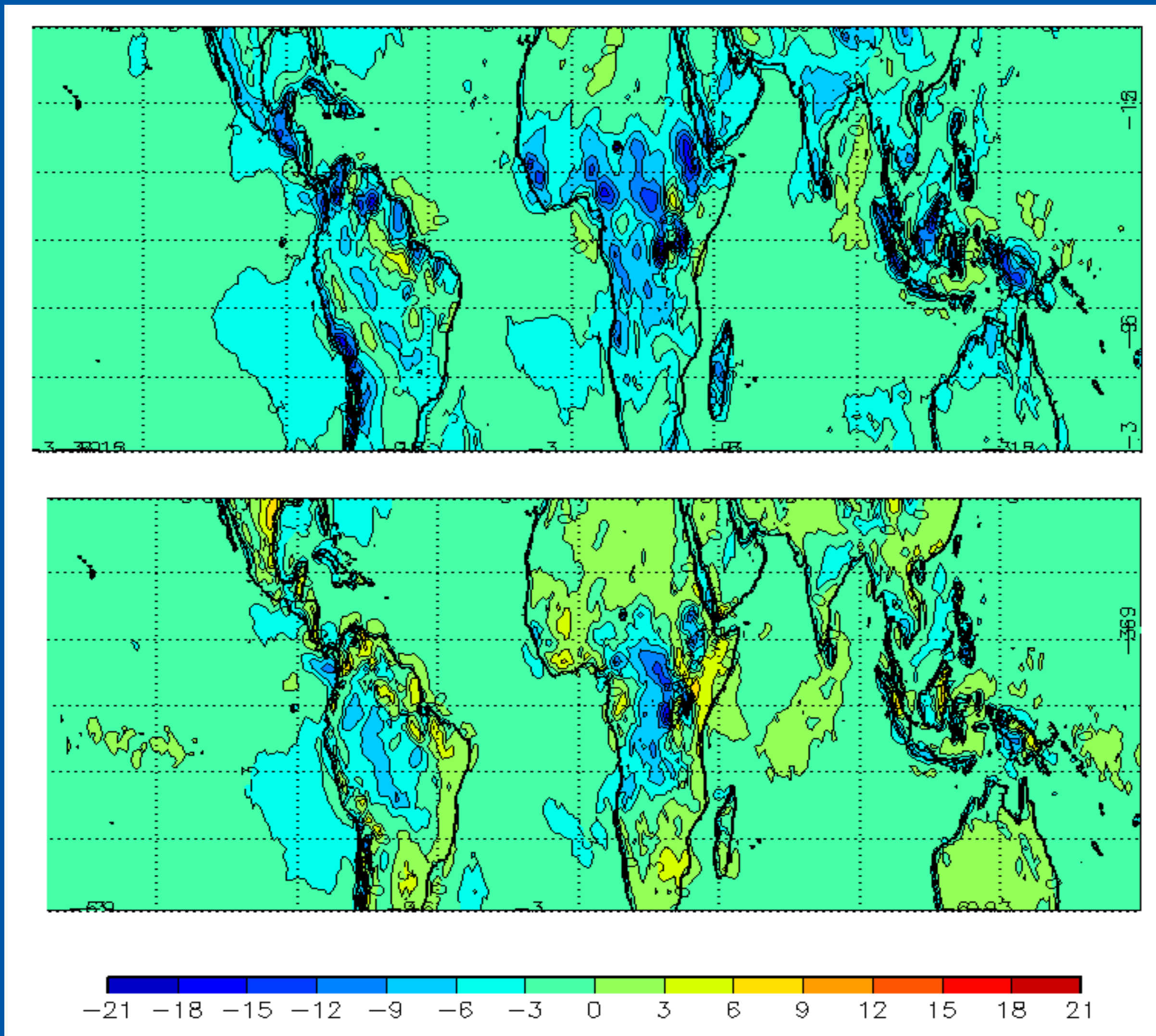


ERA-Interim

MERRA

- Shown are the differences between the climatological OLR diurnal cycle amplitude from ERA-Interim and MERRA with CERES observations.
- The results indicate that over land the reanalysis data sets significantly underestimate the OLR diurnal cycle amplitude.
- This error is mostly drive my a weak LWCF diurnal cycle amplitude.

Reanalysis diurnal cycle bias: LWCF amplitude

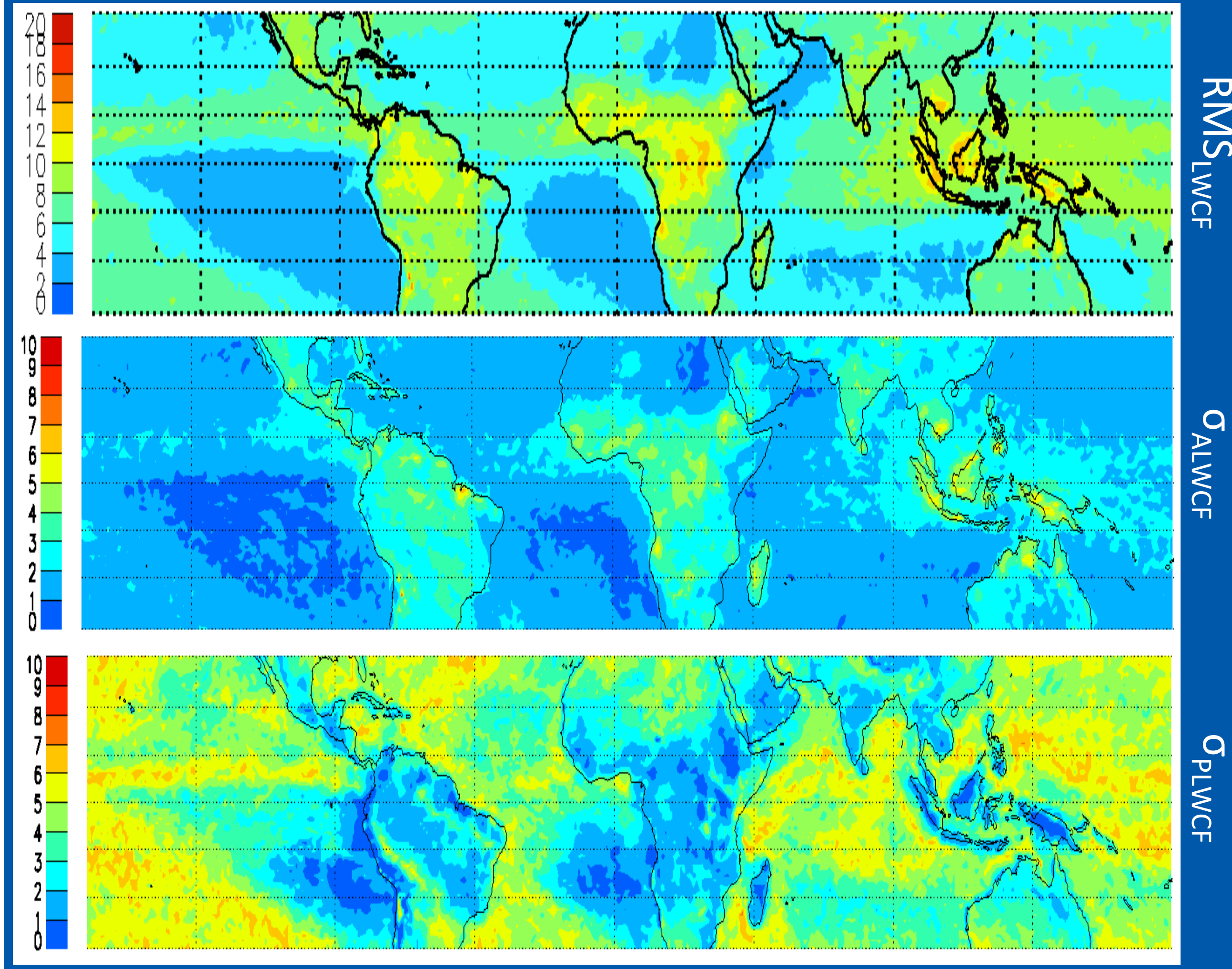


ERA-Interim

MERRA

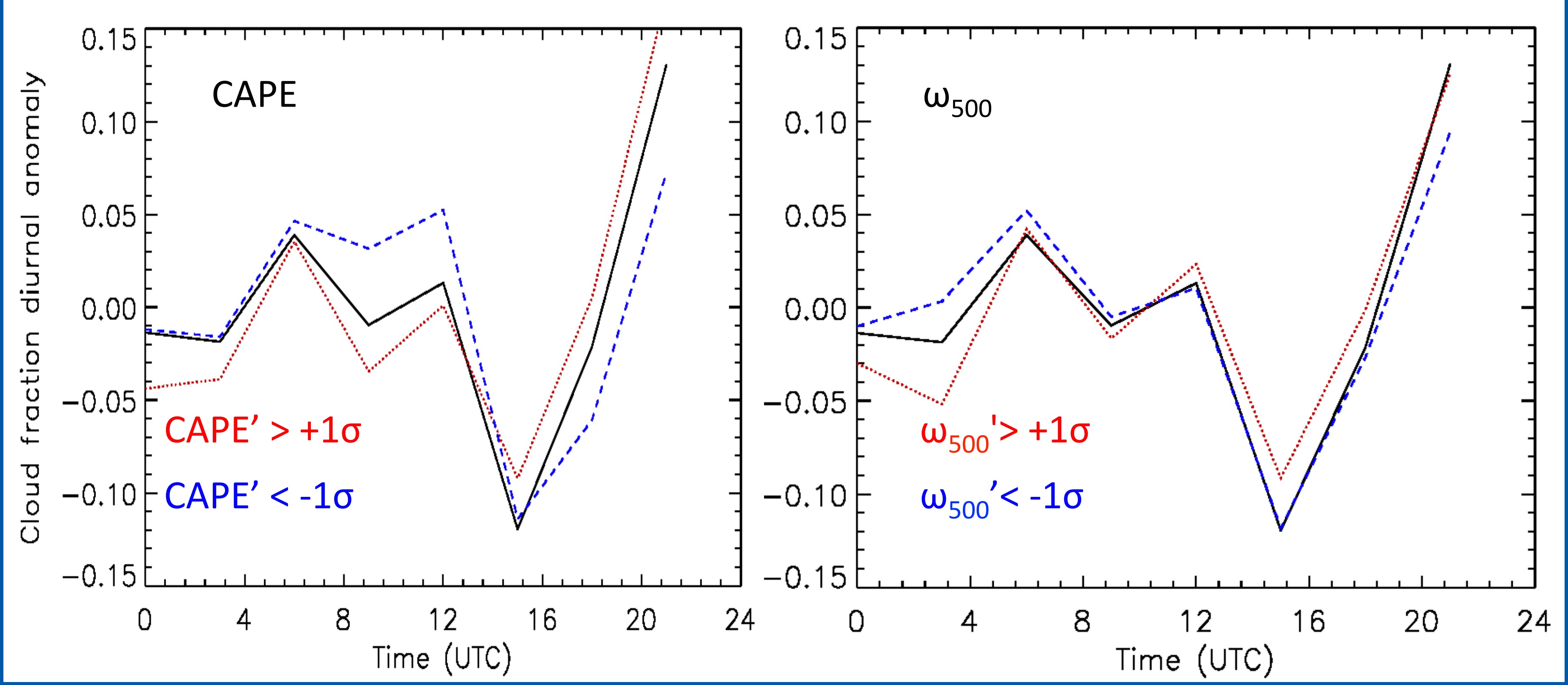
- Shown are the differences between the climatological LWCF diurnal cycle amplitude from ERA-Interim and MERRA with CERES observations.

Harmonic vs. RMS Method: LWCF



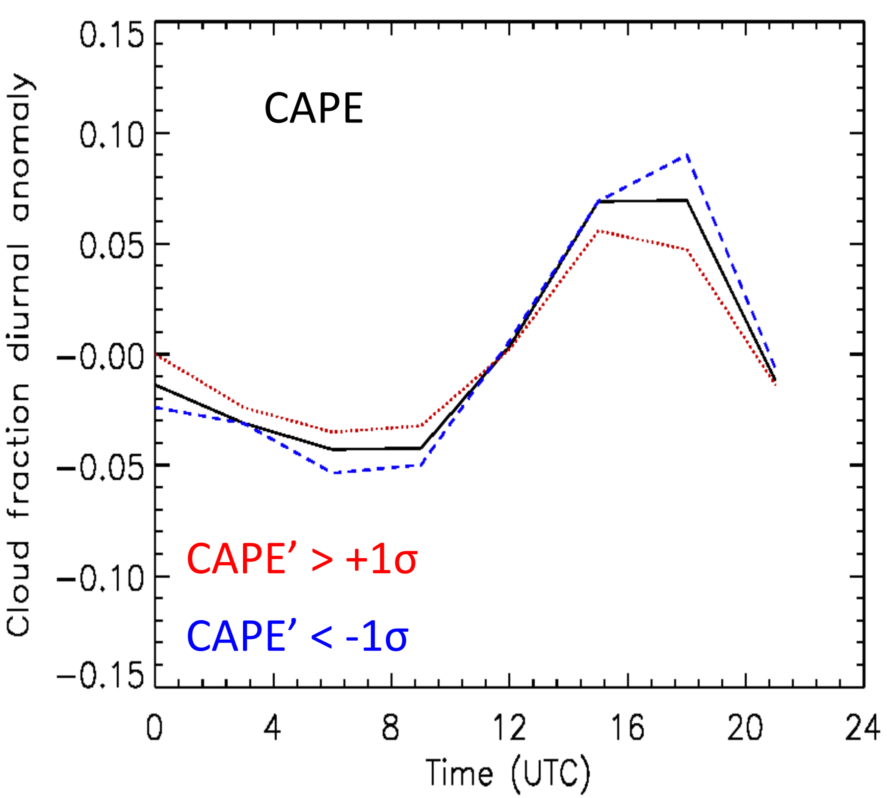
- Same as previous but for LWCF.
- The main point here is that the RMS method cannot distinguish between amplitude and phase contributions.

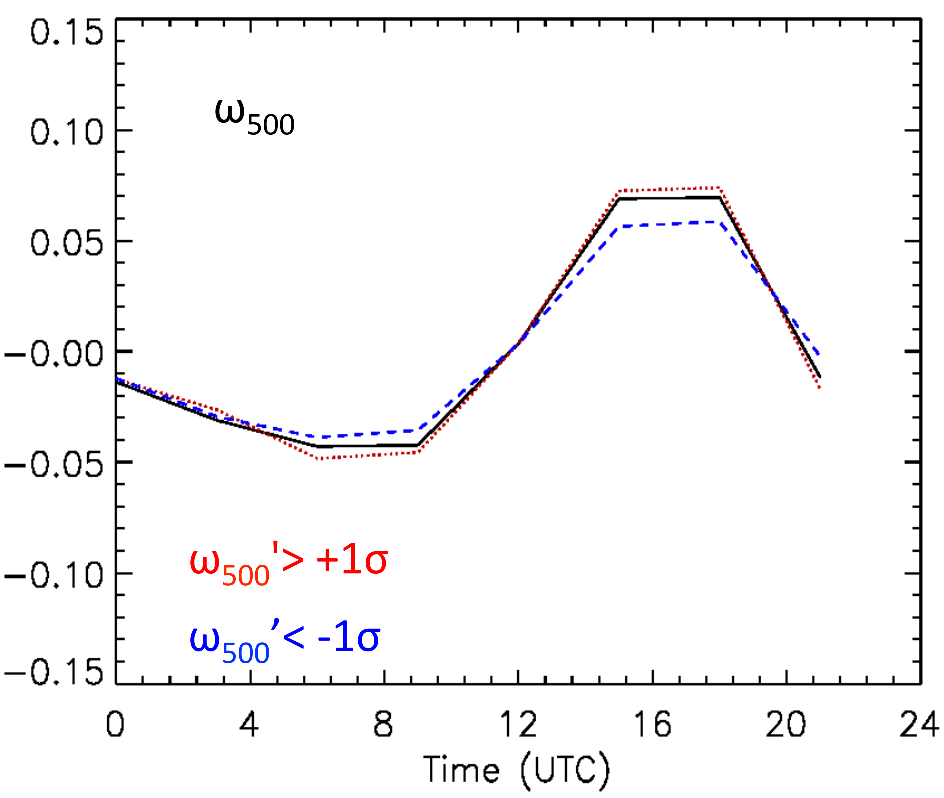
South America Convective Region: High Clouds



High cloud fraction diurnal cycle amplitude and phase show a sensitivity to CAPE and ω_{500} anomalies.

South America Convective Region: Low Clouds





Low cloud fraction diurnal cycle amplitude and phase show a sensitivity to CAPE and ω_{500} anomalies.